# Picking Up STEAM: Educational Implications for Teaching with an Augmented Reality Guitar Learning System

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**Abstract.** Incorporation of the arts into the current model of science, technology, engineering, and mathematics (STEAM) may have a profound impact on the future of education. In light of this, we examined a novel technology at the intersection of these disciplines. Specifically, an experiment was conducted using augmented reality to learn a musical instrument, namely the guitar. The Fretlight® guitar system uses LED lights embedded in the fretboard to give direct information to the guitarist as to where to place their fingers. This was compared to a standard scale diagram. Results indicate that the Fretlight® system led to initial significant gains in performance over a control condition using diagrams, but these effects disappeared over the course of 30 trials. Potential benefits of the augmented reality technology are discussed, and future work is outlined to better understand how embodied cognition and augmented reality can increase learning outcomes for playing musical instruments.

**Keywords:** STEAM, augmented reality, embodied learning, music education, Fretlight® guitar.

## 1 Introduction

The STEAM education movement is currently building momentum towards incorporating the arts into the science, technology, engineering, and mathematics (STEM) thrusts [e.g., 1]. To justify the benefits of the Arts, recent efforts by the Dana Foundation [2-3] have organized multi-university consortiums of leading cognitive neuroscientists in order to examine the relationship between learning, arts, and the brain. The consortiums have established that the arts play a critical role in the development of generalizable cognitive skills that can serve as a benefit to learning. One form of art related to a number of neurological and educational benefits is playing a musical instrument. More specifically, music training may lead to increases in brain plasticity across the lifespan [4], processing of both musical and non-musical auditory stimuli [5], and demonstrable improvements in reading comprehension and math skills [6].

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Previous research has highlighted a need to incorporate quality music training more heavily into education at all levels, with early stages being particularly more beneficial [2-3], [5]. However, there are limitations to the distributed nature in which traditional music learning often occurs [7]. Recent advances in computing technology have sought to mitigate the limitations of distributed learning materials through the use of augmented reality, particularly for learning to play the guitar [8-9]. These systems were experimental and faced several shortcomings. The present research seeks to extend this line of work by examining an augmented reality guitar learning system that may foster an embodied learning environment. Embodied learning environments facilitate learning by allowing individuals to be engaged both physically and mentally leading to a stronger interconnection of auditory and visual stimuli with motor responses [10] and thus the integration of augmented reality musical learning systems should serve as a benefit to music education as well as STEM education.

### 1.1 STEAM and the Benefits of Arts Education

The STEAM education movement seeks to incorporate arts as an essential element to the STEM education movement [1]. More specifically, proponents of this movement claim that an integrated STEM and arts curriculum is essential to foster creativity and innovation in the STEM disciplines [11]. Over the years, a number of research efforts have tried to establish the link between learning, the arts, and the brain, though maybe none as vast as the multi-university consortiums of cognitive neuroscientists organized by the Dana Foundation [2-3]. The overarching consensus from these large research efforts was that training in the arts is correlated with generalizable educational and neurological benefits and thus the arts should be advocated for in accordance with other STEM disciplines and integrated into current educational systems at multiple levels.

Though the arts incorporate a large number of disciplines, the focus of this paper is specifically on the benefits of music education, and more specifically, guitar training. A benefit to STEM education found by Spelke [in 2] was that intensive and prolonged music training was associated with better performance in core brain systems associated with geometrical tasks. This claim is also supported by Vaughn [12] who used meta-analytic techniques to examine this association between music training in both geometrical and spatial reasoning. More generally, Jonides [in 2] found that extensive music training led to the development of enhanced memory by an increased ability to focus attention on rehearsal tasks. Likewise, Neville et al. [in 2] found that children given music training showed an increase in executive control function analogous to those given specific attention training. These findings suggest music training leads to positive benefits for learning as a function of increased attention and spatial reasoning abilities.

Additionally, Kraus, and Chandrasekaran [5] found that music training has an overarching benefit to auditory processing that includes improvements in auditory-verbal-memory and auditory attention for both music and non-music auditory signals. Further, the researchers have found that music training leads to increases in brain plasticity that are correlated with performance on executive function tasks [5], [13].

These improvements are primarily a function of practice and age during the onset of training; however, even practice at later stages in life can lead to increases in neuroplasticity [5]. In regards to the benefits of music training during early phases of learning, Skoe and Kraus [14] found that short durations of formal music training during childhood showed significant differences in auditory brain stem responses approximately seven years after formal training had commenced. Drawing from the results of this study and their prior work, Skoe and Kraus [14] conclude that there are long lasting positive benefits to music training. As such, the evidence is mounting in support of the generalizable benefits of music training, especially during early stages of education. Further, research needs to establish the educational benefits associated with certain types of music training strategies and technologies.

## 1.2 Augmented Reality Guitar Systems

Differential benefits likely result from the specific instructional strategies employed in the varying types of musical training that individuals receive. Rather than detail the number of differences resulting from music training types, one solution for mitigating a pervasive issue across all types of music training is proposed in the context of electric guitar training. Specifically, one barrier to music learning is the distributed nature of the materials required for learning an instrument [7]. This poses a problem during learning of new music material as it is often presented in an abstract form such as notation, guitar tablature, or diagrams that have to be memorized and translated in some form to the instrument (see Figure 1 for example diagram). A related finding to this notion stems from piano learning research where Lim and Lippman [15] found that performance was greater for participants who were able to physically practice a piece rather than attempt to memorize it. Though the piano research utilized distributed materials, it suggests that performance may be improved though the stronger coupling of the learning materials with performance on that actual instrument.

One approach to mitigating the problem with distributed learning materials may be overcome by integrating augmented reality technology with guitar training. Augmented reality involves the mixing of the physical world with digital information [16]. Liarokapis [8] and Motokawa and Saito [9] have developed experimental augmented reality guitar learning systems that represent a step towards integrating the digital representation of the material to be learned with the physical instrument; however, these systems are experimental and not easily accessible to those less technically inclined. A recent commercially available product, known as the Fretlight® guitar (Optek Systems, Inc.), includes an LED circuit board underneath the fret board. When coupled with the included computer software, the guitar is thought to help individuals at any level of musical experience to advance their performance. The company claims their guitar is useful because it displays the information guitar players need (i.e., where to place their fingers) right where they need it (see Figure 1). The benefits of this device seem clear though they have not been empirically evaluated. Utilizing the Frelight® guitar will allow for an examination of sensorimotor learning processes within the framework of embodied and enactive cognition.

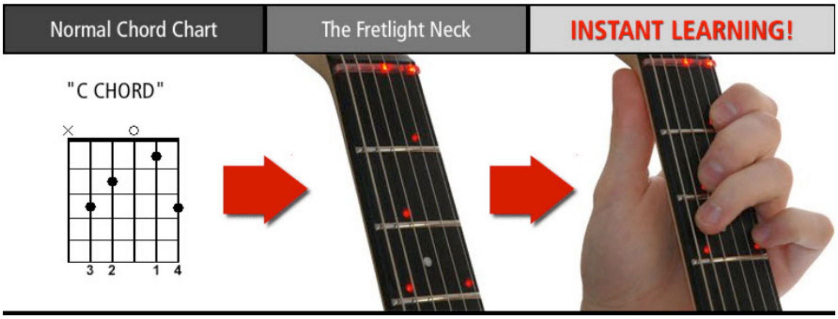


**Fig. 1.** The leftmost part of this image represented a standard chord diagram utilized in learning to play the guitar. The center image represents how the Fretlight® guitar would display the same information and the rightmost image represents how an individual is able to see and place their fingers in the proper location.

### 1.3 Embodied and Enactive Learning

Kagan [in 3] advocates for the importance of arts in education because the arts are able to multi-modally engage the mind; thus leading to the integration of motor, perceptual, and cognitive skills. This emphasis on the mind is somewhat misleading as the body plays a major role in music learning through the sensorimotor system. Specifically, sensorimotor integration is the result of both learning and practicing a musical instrument. That is, these activities lead to the association of motor actions with certain auditory signals and visual information resulting in strengthened connections between the auditory and motor regions of the brain [4]. Further, Kraus and Chandrasekaran [5] found that children under seven that were given musical training show superior sensorimotor integration than those whom received training later in their lifetimes. This notion suggests the temporal occurrence of music training makes a difference such that sensorimotor integration is stronger when music training occurs earlier in life.

Two theories that are particularly relevant for understanding the sensorimotor learning processes are embodied [e.g., 18] and enactive cognition [e.g., 17]. Recent advances in the cognitive sciences have supported the embodied and enactive theories using the exemplar of music cognition [19-21]. That is, music and more specifically, the process of learning to play a musical instrument, is not an amodal cognitive process that occurs independently of the environment. Rather, the embodied and enactive theories claim that there is an inextricable multi-modal link between the environment (e.g., the musical instrument) and the brain created through the body's sensorimotor system [20-21]. Given this notion, knowledge of music and how to play an instrument can be thought of as arising from the co-occurring perceptions and actions apparent in the learning process.

Along these lines, embodiment has been identified as a key theory for the design of augmented and mixed-reality learning environments as it supports learning by allowing individuals to be engaged both physically and mentally and thus leading to sensorimotor integration [10]. So far, researchers have not attempted to integrate the embodied approach to musical learning with mixed or augmented reality learning systems. This research represents such an attempt by utilizing the Fretlight® guitar in which digital information displayed on the guitar, rather than through distributed materials, visually indicates the location to place the fingers. As an individual places their fingers and plays the notes indicated by the Fretlights®, motor actions couple with the perceptions of the auditory signals and visual information and thus theories of embodied and enactive cognition likely underpin learning with the Fretlight® guitar.

### 1.4 Research Hypotheses

The goal of this research is to compare the learning processes that occur during training of the A minor pentatonic scale with the Fretlight's LED system compared with a scale diagram (a more traditional guitar learning aid). More specifically, accuracy and precision were compared between the two conditions during both the learning of the scale as well as during a test performance in which there was no learning aid. The two conditions were compared in order to evaluate learning gains. Our hypotheses were as follows:

- H1: Performance during training, in terms of accuracy and precision, for the Fretlight® guitar condition will be better than in the diagram condition.
- H2: Test performance, in terms of accuracy and precision will be better in the Fretlight® guitar condition.

## 2 Method

### 2.1 Participants

55 undergraduate students from the University of Central Florida voluntarily participated in this study. There were 30 female and 25 male participants. Participants voluntarily participated in exchange for class credit. Eligibility for this study was restricted to right-handed individuals who had no formal or informal stringed instrument training.

### 2.2 Experimental Design

A between-subjects design was utilized for this experiment where participants were randomly assigned to one of two levels of the independent variable (IV). The IV for this study was the learning aid that participants utilized for learning the A minor pentatonic scale. The two levels of this IV are as follows: (1) Fretlight® LED learning aid in which LED lights illuminate the scale so that participants can see the proper locations of notes embedded within the fretboard and (2) scale diagram learning aid, which is a traditional distributed method for learning the guitar consisting of a paper diagram with the notes of the scale shown on a depiction of the fretboard.

The dependent variables (DVs) of the study were participants' training and test performance ratings. In order to determine the training and test performance, a rating scale was developed to assess the accuracy and precision of each of the 12 notes of the A minor scale for each trial of the training and test performances. Specifically, the constructs of accuracy and precision were incorporated into a rating scale in which each note played by participants was assigned a value of 0 – 4 depending on whether it was a correct note and how precise that correct note was played.

### 2.3 Procedure

When the experiment first began, participants were given an informed consent document and randomly assigned to one of the levels of the IV. Then, all participants were introduced to several basics of the guitar utilizing a PowerPoint presentation with embedded videos. The presentation familiarized participants with how to hold the guitar, how to fret notes with the left hand, and how to use the right hand to pick the strings. The training information included in the presentation was based on guidelines included with the Fretlight® software. During the presentation, participants were given opportunities to practice the basics of the guitar. Participants were then trained to play the A minor pentatonic scale over approximately 30 training trials with one of the two learning aids (Fretlights® or diagram). All participants used the same guitar. For the training, participants were asked to try their best to play through the whole scale and to continue on to the next note if they skip or mess up a note in the scale. To determine the extent to which participants learned to play the scale, they were required to complete a test performance without the learning aid (i.e., Fretlights® or diagram were removed) for 10 test trials.

## 3 Results

The performance data were analyzed using a 2 x 4 mixed ANOVA model to examine performance during the first and last training trials as well as the first and last test trials. Results indicated a significant interaction effect, $F(2,53) = 6.6$, $p < .05$, partial eta$^2$ = .112. The Fretlight® condition led to significantly higher performance ($M$ = 29.1, $SD$ = 7.72) than the diagram condition ($M$ = 24.5, $SD$ = 11.85), but only during training trial 1. Following, there was a significant increase in the diagram condition performance from training trial 1 ($M$ = 24.5, $SD$ = 11.85) to training trial 2 ($M$ = 31.1, $SD$ = 8.1). There were no significant differences between or within conditions during either of the testing portions of the experiment (see Figure 2).

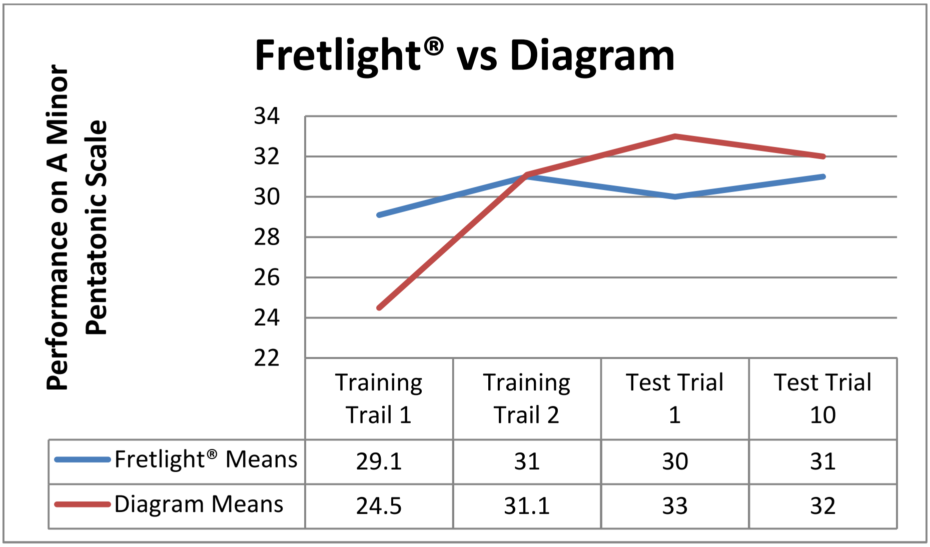


**Fig. 2.** Comparison of performance on A minor pentatonic scale between the Fretlight® and diagram conditions

# 4 Conclusions

## 4.1 Discussion

Based on these data, it seems there is some support for H1 during the initial training trial difference. That is, participants in the Fretlight® training condition performed better than those in the diagram training condition. However, because this is followed by a convergence in performance at the end of the training, we cannot conclude full support for H1. Rather, we can develop a new hypothesis: Performance during initial training sessions with the Fretlights® will be greater than those in the diagram condition though, performance will converge as the number of training sessions increase. Further, H1 was not supported as no significant differences between the test performance scores were found between the two conditions.

## 4.2 Implications

These data demonstrate that 1) embodied learning through the Fretlight® guitar may create a lower "barrier to entry" for learning to play the guitar and 2) and that we must attend to training design implications. Specifically, Fretlight® training programs needs to make it explicit whether the aim is for the device to be utilized in the real-world (i.e., during a performance) or just as a training aid to make learning easier (this is likely the case). For example Tang, Owen, Biocca, and Mou [22] assessed the effectiveness of an augmented reality system for an object assembly task with other forms of media; however, they did not compare how participant performance was influenced when the training medium was removed, as was done in the present study. Further, if the aim is to eventually play the guitar without the aid of the Fretlights® then the findings from this study suggest there is a need for some form of scaffolding incorporated into training in which the individual transitions from use of the technology to non-use.

More broadly, future research needs to examine the specific tasks and components of learning a given musical instrument utilizing measures to better comprehend which aspects of learning to play a musical instrument are associated with specific cognitive benefits especially more longitudinally and at different ages. Some constructs that may be beneficial to examine include tests of spatial-temporal reasoning, reading comprehension, auditory discrimination skills, and neuroplasticity [4-5], [23].

In sum, a large body of research has amassed pointing to long term benefits of music training and support for incorporating the arts, specifically music training, into STEAM education. This research represents a unique exploration of learning through a novel augmented reality guitar learning system and as novel technologies are developed for advancing the science of learning a musical instrument, researchers must examine the extent to which benefits inherent to the traditional music training process still remain.

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